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ABSENCE OF DECONNEXION SYNDROME IN TWO PATIENTS WITH PARTIAL SECTION OF THE NEOCOMMISSURES[1]

BY

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INTRODUCTION

THE interpretation of symptoms produced by lesions of the corpus callosum has long been subject to confusion introduced in part by uncertainties about the extent to which remaining portions of the commissures can compensate for the loss of the damaged structures. In an early series of commissurotomy patients of Van Wagenen and Herren (1940) studied by Akelaitis and others (Akelaitis, 1944; Smith, 1952), distinct callosal symptoms were reportedly absent. In most cases the posterior part of the callosum and anterior commissure were left uncut. Also, two operations were often involved, including cases of anterior commissure section. By contrast, complete section of the entire corpus callosum and anterior commissure combined in the single operation of P. J. Vogel (Bogen and Vogel, 1962; Bogen *et al.*, 1965; Bogen *et al.*, 1969) has since been shown to produce a broad array of definite and lasting behavioural symptoms that have been directly correlated with the loss of the fore-brain commissures (Gazzaniga *et al.*, 1963, 1965; Sperry, 1968*a*, *b*; Milner *et al.*, 1968; Sperry, 1970). The discrepancy may lie in part in the potentially high capacity of the human brain to use small, intact remnants of the commissures to compensate for and conceal disconnexion deficits, aided by symbolic cross-cuing strategies. Direct evidence, however, has been lacking.

Another major source of confusion in the interpretation of callosal lesions comes from the complicating effects of coexistent extracommissural cerebral damage. With respect to split-brain symptoms in both the animal and human studies, the potentiating effect of the associated cerebral damage has been emphasized, along with the great diversity of symptoms that may result from different combinations of various commissural and extracommissural lesions (Sperry *et al.*, 1969). Where partial injuries to the corpus callosum have been produced by vascular or neoplastic lesions, specific

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disconnexion deficits have been described, as severe in some cases as those observed after complete commissure section (Geschwind, 1965).

These questions are considered here against further evidence from a study of two recent patients of Vogel, both of whom had undergone extensive commissurotomy for control of epilepsy. This included division of the anterior commissure and a major portion of the corpus callosum; but it differed from the previous commissurotomy operations of Vogel in that the splenium of the callosum was spared in both the present cases. This procedure was followed in the hope, so far sustained, that the operation would be extensive enough to reduce seizure activity and transmission, while at the same time preserving sufficient cross-fibre communication to avoid some of the symptoms of complete hemispheric disconnexion. The effect of these partial surgical divisions compared with those produced by complete section provides new information about the functional capacity of a small intact portion of the corpus callosum.

The preserved splenium in the two present patients was roughly comparable to the spared region of the callosum of some previously described cases (Sweet, 1941; Kaplan *et al.*, 1961; Geschwind and Kaplan, 1962; Schott *et al.*, 1969) having vascular or neoplastic damage to the anterior parts of the callosum. Hence, a comparison can be made of the behavioural deficits caused by callosal lesions about equal in extent but produced by surgery on the one hand, and by different pathological lesions on the other.

Case Summaries

D. M. (WMH. 49-28-00, UCLA 020-71-88) had psychomotor and *grand mal* epilepsy beginning at the age of 11, shortly after a closed head injury to which his seizures were attributed. The generalized convulsions, but not the automatisms, responded to treatment. Typical spells involved uncontrolled running, waving of arms, urinary incontinence, and screaming. A right foot drop was attributed to poliomyelitis at the age of one, but neurological examination showed this weakness of the right leg to be associated with a slight increase in knee and ankle jerks, and a questionable plantar reflex. Skull X-rays, brain scan, bilateral carotid angiogram, and pneumoencephalogram were normal. Serial EEGs, including sphenoidal electrodes, showed independent left and right temporal foci. Intra-carotid amytal confirmed speech lateralization to the left hemisphere. Full scale WAIS score before operation was measured to be 76 while the patient was taking a daily dose of one gramme primidone and 400 mg. phenobarbitone. At operation on 31.7.68 (age 23) the anterior commissure was cut as was the anterior 5 cm. of the corpus callosum and presumably all of the underlying hippocampal commissure. The massa intermedia was absent. The post-operative course was without incident and recovery was remarkably smooth and rapid as compared with the usual course following complete neocommissurotomy. Within two hours of the operation, the patient spoke well, showed no apraxia and readily named any finger of either hand when it was touched. During the first year after operation, the patient had many "absences" with adversion to the left, lasting several seconds; but the screaming, incontinence, and the violent automatisms characteristic of the preoperative spells have not recurred. The patient's interictal disposition improved greatly.

N. F. (WMH 50-31-61, UCLA 037-43-73, LAGH 83-22-60) had seizures beginning at about age 14. These often began with hallucinations and bizarre, violent behaviour. At other times she became suddenly unresponsive and fell, often with injury. Both sorts of attack sometimes went on

to a generalized convulsion. Neurological examination, skull X-rays, brain scan, bilateral carotid angiogram and pneumoencephalogram were noncontributory. Many EEGs, including sphenoidal recording on two occasions, showed independent temporal foci, more severe on the right. A right carotid amytal injection produced flaccidity of the left arm with a barely detectable slurring of speech. Full scale WAIS score before operation was measured to be 101 while taking a daily dose of diphenylhydantoin 400 mg., phenobarbitone 200 mg., and primidone 500 mg. At operation on 17.1.69 (age 26) the anterior commissure was cut along with the anterior 5 cm. of the corpus callosum and presumably all of the underlying hippocampal commissure. The section could be seen to include all of the genu and body and the anterior part of the splenium. The massa intermedia was absent. Within two hours of operation she spoke well, had no apraxia, and readily named any finger of either hand when it was touched. Her recovery went well until the seventh post-operative day, when she was discovered in the course of a persistent convulsion of the right limbs with a temperature of 107. The convulsions eventually subsided after 60–90 minutes, leaving the patient with a completely flaccid hemiplegia on the right side. For twelve hours there was no speech or co-operation with verbal request, although the left hand was used in a purposeful, well co-ordinated manner to manipulate objects. This severe, prolonged unilateral seizure was associated with acute atrial fibrillation and hepatitis, subsequently attributed in part to the anæsthesia. The cardiac and liver conditions rapidly improved. The aphasia and hemiplegia gradually cleared so that three days after onset she had a very weak grip in the right hand; and a week after onset, she was using her right hand effectively and conversing with only mild dysarthria. A minimal inco-ordination of the right hand has since persisted. Except for this one episode of unilateral status epilepticus, the patient has had virtually no seizure of any kind throughout the testing period since the operation.[1] Her interictal disposition is about the same as before, though there is still some memory defect six months afterwards.

Method

The tests reported here were conducted over a twelve-month period beginning a few days before operation. Most of the testing methods were similar to those we have used previously (Sperry *et al.*, 1969) for detecting impairments in interhemispheric cross-integration. In general, these procedures depend upon controlled lateralization of cerebral activity obtained in various ways, as by restricting the inflow of sensory information to one hemisphere, and employing functions already lateralized such as speech and writing. As a rule, the *inter*hemispheric performance is compared with the *intra*hemispheric version of the same task; and both of these with the normal performance of unoperated controls. Where specific comparisons are drawn for previously described patients with nonsurgical lesions, the tests were also adapted to conform with the published account. Testing of the present two patients is still in progress; the aim of the present report is not to present a comprehensive account of their symptoms but to point out the striking contrasts already evident between the behavioural effects of complete and incomplete fore-brain commissurotomy, and of surgical and nonsurgical lesions of comparable extent.

Observations

Verbal Identification of Visual Stimuli

A total of 50 pictures of letters, words, objects, or common street scenes were flashed at 1/10–1/25 of a second on a rear-projection screen. Each subject sitting about 18 in. before the screen directed his gaze at a central fixation point. The images were projected well within each visual field ($>5°$ from the mid-line) and extended as much as 30° laterally for some of the longer words and the street scenes. The letters and objects varied in size but all were large enough to be easily read and recognized. The schedule of tachistoscopic presentations was varied on a predetermined

[1]Minor absences without psychomotor activity have since appeared occurring as often as once per week.

schedule to the left and right visual fields such that the subjects could not predict where the next stimulus picture would appear.

It was found that both subjects were able to read letters and words or describe objects and scenes equally well for either visual half-field. They responded with equal assurance whether the stimuli were flashed to the right or to the left of the fixation point, showing no evidence of the specific left field difficulties that have been observed under the exact same conditions by subjects with complete callosal section. Some difficulty with words of 4 letters or more was apparent in both subjects but was not noticeably worse in the left half visual field.

Verbal Identification of Tactual Stimuli

Common household objects, and plastic numbers and letters measuring 4–6 cm. high were placed one at a time in one or the other of the subject's hands. These stimuli were screened from view at all times and were controlled for relative size, temperature, sharp points, and other bilateralizing cues.

As in the visual tests, and in contrast to the performance of patients with complete commissurotomy or with lesions caused by pathology (Geschwind, 1965), these two patients typically named or described the objects, numbers, and letters easily and without hesitation when using either the left or the right hand. D.M. had trouble at times naming certain items such as a can opener or paper clip that N.F. and normal subjects readily identified, but D.M. displayed the same difficulty with either hand.

Verbal Identification of Olfactory Stimuli

Typical aromatic substances (perfume, coffee grounds, mint extract, etc.) were placed in small glass vials and presented under the subject's nose with vision blocked so that the only cues were olfactory. Pre-trials with both nostrils open established a level of proficiency for odour identification before actual testing of single nostrils. Six vials with different odours including water were presented on a pseudorandom schedule one at a time to either the right or left nostril, with the other being pinched shut; the subject was to name the odour after a gentle inhalation.

In three testing sessions D. M. succeeded with verbal identification of aromas from either the right or the left nostril, although his level of proficiency was greater for the left. His answers after presentation to his right nostril were less often correct and made with generally less confidence. Sometimes when trying to name the right nostril odours he would say, "I don't know," "I forget," or "I didn't get that one." In his best performance at a session where five different odours were presented on a balanced right-left schedule, he correctly named 28 out of 32 odour samples in his left nostril but only 16 out of 32 in his right. Patients with complete section of the callosum were unable to name odours in the right nostril above a chance level ($P > 0{\cdot}05$) but were able to correctly identify the same right nostril odours by non-verbal readout (Gordon and Sperry, 1969). Pre-operative data on N. F. showed a very low ability to recognize the aromas normally with both nostrils open and total failure with either one alone. This remained unchanged after surgery.

Visuo-tactual Matching

Two sets of objects were used for visuo-tactual cross-modal identification. The first set contained 8–10 common household objects similar to those used in the tactual naming task. The second set of stimuli consisted of 6–8 quasi-geometric shapes about 1 in. in diameter and cut from 1/8 in. plexiglass. They were designed so that they could not easily be described verbally. Photographic slides of these same objects and shapes were flashed at 1/10 of a second on the rear-projection screen while the subject held his gaze on a central fixation point. After the picture was flashed to one or the other side of centre the subject was touched lightly, according to a predetermined balanced schedule, on one or the other hand with which he was then to retrieve the object which had been pictured.

N. F. obtained a near perfect score of 8 or 9 correct out of 10 trials with each of the four visuo-tactual combinations. D. M. scored 50–70 per cent correct with the errors scattered about evenly between the crossed and uncrossed visual field-retrieval hand combinations. With respect to these tests it seemed to make no difference with which hand the object was retrieved nor in which visual field the stimulus had been flashed. The results were much the same when the test was repeated with the printed names of the household objects instead of the actual pictures.

Tactual-tactual Matching

The same two sets of objects and shapes used in the above cross-modal task were presented one at a time behind a screen to the right or left hand. After one had been briefly palpated, the test item was then transferred to a group of 6–8 similar objects also screened from sight but within easy reach. The subject's task was to search for and find the given item and hold it up for the examiner. Retrieval with the hand which had originally felt the object was compared with retrieval with the other hand.

Again, contrasting with complete commissurotomy patients, no deficits in the crossed-matching were observed: correct cross-retrieval with the opposite hand seemed to be performed about as readily as direct retrieval with the same hand.

Olfactory-tactual Matching

The aromatic substances used in the olfactory naming were again presented one at a time to the right or left nostrils. Using procedures described elsewhere (Gordon and Sperry, 1969) the various odours were matched with corresponding objects (e.g. lemon-plastic lemon, perfume-small perfume bottle, etc.). Instead of making a verbal response, the subject was instructed to find and select by touch the object which was most appropriately paired with the odour. All visual cues were blocked so that only the olfactory information from the stimulus could be paired with the touch of the corresponding object.

D. M. performed well above chance ($P < 0{\cdot}01$) with scores consistent with those reported above for the naming of olfactory stimuli. He selected the correct objects from 5–6 choices with either hand nearly every time when the aroma was presented to the left nostril but was correct in only 50 per cent of the trials for odours presented to the right. N. F. failed to perform this task consistent with her incapacity to identify the test odours under the normal control conditions.

Hand and Finger Movements to Verbal Command

Common hand gestures like "Make a fist," "Wave good-bye," or "Comb your hair" were easily performed by both subjects with either left or right hand upon the verbal request of the examiner. These tests were extended into more finely differentiated movements of thumb and fingers like "Make a circle with your thumb and first finger," "Cross the first two fingers," or "Touch your little finger with your first finger."

These also were performed successfully and without difficulty with either hand.

Cross-matching of Cutaneous Localization and Hand Postures

With the subject's hands blocked from his own view, the examiner lightly touched with a small pointer single points on finger segments of the right or left hand. The subjects readily indicated the exact area stimulated by touching the spot with the thumb of the same hand. They were also able to cross-locate the corresponding spot on the other hand with the thumb of that hand, a task that cannot be performed by patients with complete section of the callosum. In another test, the examiner positioned the fingers of one of the subject's hands in specific fixed postures and the subject was then required to copy the imposed finger positions with the opposite hand. In other versions of this task the imposed posture was erased by relaxation of the hand after which the subject was to remember the posture and then replicate it a moment later with the same hand or with the opposite hand.

Both subjects carried out all three versions of this task with little or no difficulty. They could also form these same finger postures with either hand when a demonstration picture of the hand in these same positions was flashed at 1/10 of a second to the left or right visual field.

Simultaneous Bilateral Movements

The subject was instructed by demonstration to extend both his arms forward from the shoulders and to move them together in synchrony up and down at a rate of 2–3 times per sec. for a 15-sec. test period. The task was to maintain a consistent motion so that both limbs would remain in phase with each other. The test was repeated for both hands with the forearms held stationary, and then with both index fingers with hands resting on the table.

D. M. had no problem in keeping his two arms, hands, or fingers moving in synchrony up to the prescribed frequencies. N. F. performed satisfactorily with both arms extended, but could not maintain synchrony with the hands or index fingers. However, N. F. was also unable to maintain a steady rhythm with her right hand alone and these motor deficits may therefore reflect the residual effects of the transient right hemiplegia which she had for a week after operation.

Copying and Writing

Both subjects were right-handed for writing before operation (though D. M. was found to be left-footed and left-eyed by subtests of the Harris Test of Lateral Dominance). Both continued to write well with the right hand after operation, although N. F. complained that her ability was somewhat below her pre-operative level. Both subjects could also write whole sentences with the left hand, either

spontaneously or to dictation using a cursive script which was quite legible but less so than that of the right hand. No defects were seen in either hand for copying letters, numbers, or words. Copying of hand-drawn representations of two- and three-dimensional forms appeared to be equally good with either hand. In earlier tests conducted within the first month after surgery, however, each patient appeared to be at a greater loss to draw a Necker cube with the right hand than with the left. In contrast to most patients with complete commissurotomy (Bogen, 1969), this was a transient effect that was no longer apparent in later tests.

Formboard Learning

This test was applied to D. M. and N. F. for comparison with a twenty-year follow-up report of another surgical case with a minimal splenial remnant (Goldstein and Joynt, 1969), but differing from the present cases in that there was an intact anterior commissure. Three to five wooden blocks formed into geometric shapes to be used with a simplified Seguin-Goddard Formboard were the discriminanda for the learning task. There were 6 different formboards each with its own set of shapes, but no more than three boards were given in any one test session. With vision excluded by a blindfold throughout the test, the subject removed the shapes one at a time from a box on his lap and, using only tactual cues, placed each block into the corresponding depressions on the formboard in front of him. The total time needed to insert all blocks was recorded and the task was repeated with the same hand until the performance became consistent showing no further improvement. The first trial needed about 3 minutes for each subject but the time was reduced to half by the sixth trial. Then the other hand was tested to see if the resultant improvement of practice would transfer. The first hand used to learn the formboard was alternated as each new formboard set was presented.

In D. M., transfer was virtually complete. He succeeded in nearly every instance in placing the shapes in the proper spaces on the first trial with the second hand as quickly as on the last trial with the original hand. Whether it was right or left, the second hand benefited markedly by what the first hand had learned. This result is in contrast to that of a report of similar testing in the twenty-year follow-up case where relearning was needed before the second hand could complete the formboard as quickly as the practised performance of the first hand. N. F.'s scores suggested at least partial transfer and proved to be more difficult to interpret because of a consistently low performance on the right side due to the clumsiness of her right hand.

Discussion

The results on these two patients are consistent. Hardly any of the symptoms which follow the more extensive surgical separation of the hemispheres have been found. In sharp contrast to previous cases with complete fore-brain commissurotomy (Gazzaniga *et al.*, 1963, 1965; Sperry, 1968*a*, *b*; Gordon and Sperry, 1969; Sperry *et al.*, 1969), these patients with the splenium preserved can read words and letters flashed to the left half-fields of vision; and they can name, describe, write, copy, and draw letters, words, numbers, objects, or subtle shapes presented for identification to the left hand. Even olfactory stimuli could be named by D. M.

from either nostril although one might expect, on anatomical grounds, that interhemispheric transfer relating to olfaction in particular might be dependent upon the anterior structures sectioned in these two patients. These subjects also performed a great variety of nonverbal cross-integration tasks. Visual or tactual stimuli projected initially to one hemisphere were easily matched with those projected to the opposite hemisphere under conditions of unimodal and also transmodal presentation. The findings show the remarkable extent to which the small intact posterior sector of the corpus callosum can be used to attain functional cross-integration between hemispheres.

The findings contrast with reports for cases of vascular and neoplastic lesions involving comparable portions of the corpus callosum where the symptoms have included anomia for manipulated objects, apraxia for verbal commands and agraphia—all specific to the left hand (Sweet, 1941; Kaplan *et al.*, 1961; Geschwind and Kaplan, 1962; Saul, 1969; Schott *et al.*, 1969). This marked difference between the symptom effects of surgical and pathological lesions emphasizes the need for extra caution in attempting to assess commissural functions in the presence of extracommissural complications. The damage produced by neoplasms, being progressive in nature may nullify any compensatory and restorative processes that operate with a stabilized lesion. Conversely, "disconnexion" symptoms produced by a non-advancing lesion may disappear with time, as in a case where a ruptured aneurysm caused infarction of the anterior callosal and paramedian areas (Saul, 1969). Also, a few of the effects are described three months following surgical removal of an early stage lipoma in the anterior callosum (Heene, 1966). The appearance and cause of disconnexion symptoms associated with callosal lesions appear to depend also upon age factors and upon the degree to which early cerebral injury may have encouraged compensatory reordering of hemispheric and commissural mechanisms (Nebes *et al.*, 1969). The present results emphasize how allowances must be made for the functional capacity of even small intact commissural remnants that are left uncut either by intention or by accident.

It is clear from the present two patients that preservation of the posterior callosum carries major functional advantages that strongly favour partial callosotomy over complete section, provided the therapeutic benefit is sustained. The posterior sector of the callosum is found in the present individuals to transfer highly detailed information of different sensory modalities. In earlier reports where the splenial fibres alone had been surgically divided leaving the genu and body intact, verbal deficits were observed for the visual and tactual fields on the left side (Trescher and Ford, 1937; Maspes, 1948). Similar lesions in the chimpanzee have been found to impair interhemispheric transfer of visual information (Black and Myers, 1964). Both the animal and human studies to date highlight the importance of the splenium for interhemispheric communication and at the same time leave unsolved the problem of what functions are mediated by the large frontal sector of the corpus callosum.

Summary

Two commissurotomy patients with recent surgical section of the anterior two-thirds of the corpus callosum and anterior commissure underwent study on a large battery of tests for interhemispheric integration. Their performance was in sharp contrast to that of patients having complete section of the cerebral commissures in that these two subjects showed hardly any of the cross-integration deficits that persist for years in patients with complete section. The lack of typical commissural symptoms in these two patients stands in sharp contrast also to the reported disconnexion deficits described for patients with lesions of comparable extent in the anterior corpus callosum but produced by tumour invasion or vascular failure. The remarkable capacity of the posterior one-third of the callosum to maintain effective cross-communication between the hemispheres is demonstrated, indicating also the important potentiating effect of associated cerebral damage in the production of "disconnexion" symptoms.

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